MINISTRY OF WATER AND IRRIGATION

Water Resource Policy Support

Electric Power Plant

Identification and Pre-Feasibility Analysis of Non-Agricultural Reuse Options for Reclaimed Wastewater from As Samra

WATER REUSE COMPONENT

July 2001

(Replaces in full the draft of April 2001)

The Water Resource Policy Support activity is supported by
The United States Agency for International Development (USAID) through a
Contract with Associates in Rural Development Inc.(ARD:
USAID/ARD Contract No. LAG-I-00-99-00018-00, Delivery Order No. 800

Executive Summary

This activity targeted developing a pre-feasibility analysis for non-agricultural reuse of water reclaimed at the new As Samra treatment facilities. The new plant will be completed by 2004 - 2005, and a comprehensive program is underway to optimize beneficial uses of this new water resource. Approaches for municipal and industrial reuse of the reclaimed water were explored as a component of this program.

There has been little opportunity for developing and applying non-agricultural reuse approaches in Jordan because adequate sources from reclamation plants have not been available. Thus, non-agricultural reuse approaches and accompanying concepts represent relatively new thinking. The planning process will require input from numerous sources, including policy-makers, regulators, potential users and others as appropriate.

The first step toward developing a viable reclaimed water system is to design and operate a water reclamation plant, <u>not</u> a wastewater treatment plant. The distinction is not insignificant, and it must be recognized that a water reclamation facility should be operated and maintained like a potable water plant (Okun, 2001). Virtually every aspect of the new As Samra (and other planned reclamation) facilities must be carefully thought out from this perspective.

Various non-agricultural uses of water reclaimed at the new As Samra facilities may, under appropriate circumstances, be possible in the Amman-Zarqa basin. These uses include industrial cooling; irrigating sport areas, parks, ornamental gardens, and nurseries; toilet, urinal flushing, and air conditioning in large commercial and public buildings in newly developing areas; and construction. Successful development of a non-agricultural reuse program will depend on a number of important factors. These factors pertain to planning, treatment and distribution facilities, creating appropriate regulatory approaches, liaison with potential users, and implementation.

Planning for non-agricultural reuse will require cooperation among all concerned parties (including policy-makers, regulators of both water and wastewater, potential users of reclaimed water, key members of the public and others as appropriate). This group should establish mutually agreed upon goals and objectives for a non-agricultural reuse program, mapping out the planning process in a logical, but flexible way. Planning must address many factors, including standards setting, regulation, informing the public, reclamation facilities, follow-up, market development, financing, and design and construction of treatment, transmission and storage facilities. Acceptable level(s) of commitment by potential users should receive due attention during planning.

Preliminary surveys and interviews were conducted at two large potential industrial facilities using cooling water. These pre-feasibility investigations indicate that water reclaimed at the new As Samra plant can not be used for once-through cooling systems due to the large volumes required by these types of cooling systems. For use of As-Samra reclaimed water in recirculating cooling systems, phosphorous removal is necessary. As-Samra effluent can then exchange the current water make-up (88 m^3/hr) at the oil refinery. Refinery personnel have concerns, however, about

reliability and some water quality parameters (ammonia and organics). They are willing to discuss use of appropriate chemical additives with their chemical supplier, and express interest in possibly joining the reuse planning process.

The existing 99 MW power plant uses small quantities of cooling make-up water. However, power plant personnel suggest considering heat exchanger approaches that would replace some ground water consumption with reclaimed water while increasing plant efficiency. Both the refinery and the existing power plant, and the new 450 MW generating facility can become partners for developing realistic approaches to fulfilling their cooling and other process water needs.

Cooling water volumes will be substantial after a new power plant comes online. This facility to be sited near As Samra is reported to require cooling water at a rate of 5.5 MCM per year, while the oil refinery cooling water make-up is 0.6 MCM per year. Further studies, including pilot plant work, will be necessary components of maximizing use of reclaimed water by industrial facilities. With addition of treatment and storage capacity, the refinery and the existing power plant could substitute (i.e. exchange) virtually all ground water withdrawal with reclaimed water. At that stage, predicted expansion at the oil refinery would result in its using 3.9 MCM per year, while the power plant would use 0.61 MCM per year of reclaimed water. Note that after use, process (including cooling) water must be considered industrial wastewater and regulated accordingly.

Municipal uses of reclaimed water may, under the right circumstances, also be possible near the new As Samra plant. One approach for municipal use of reclaimed water is through constructing a dual distribution system: one for potable and the other for non-potable water. Economics of constructing dual distribution systems can be favorable when new areas are being developed. This approach can be considered for the East Zarqa Planning Area, the former site of a military camp, which is to house 450,000 persons within the next fifteen years, and will include commercial, public, and residential construction. While not recommended for residential reuse here, a dual system in this area could serve numerous public and commercial needs.

Appropriate standards must be developed for public or other uses that could result in incidental human contact. These uses include cooling towers at the oil refinery, where large quantities of mist contacts workers. The following is recommended: filtration of secondary effluent, chlorination to 1 mg/l and maintained at 0.5 mg/l in the distribution system, and a maximum turbidity average of 2 NTU (with a maximum of 5 NTU). Requirements including signs, back-flow prevention, and other construction necessities must be codified.

A distribution backbone (the HZR option) was considered and costs were estimated for this system to feed reclaimed water to the two power plants, the oil refinery, and the East Zarqa planning area, while allowing for future growth. The system capital cost was estimated to be approximately 14,900,000 and 18,500,000 JD in case phosphorous removal was practiced in the primary clarifier and after secondary treatment, respectively. Estimating that 6.6 MCM per year of reclaimed water are sold at start-up and that the system is financed at 6.5 % for 25 years, reclaimed water charges would be approximately 0.25 and 0.35 JD per cubic meter, respectively. When future use reaches 13 MCM/year and operates at 24 hours a day, reclaimed water charges would be reduced to about 0.16 and 0.23 JD per cubic meter, respectively (because increasing reclaimed water sales would be paying off a fixed annual loan payment). The proposed system is expandable by adding storage and pumping facilities.

The two types of phosphorous removal by lime should not be compared based only on cost. The two-stage tertiary lime treatment reduces the concentration of other scale forming constituents in addition to phosphorous. This would allow for higher recirculation ratios in cooling towers, which would lead to lower makeup water consumption and lower blowdown discharges. Zero discharge from cooling towers to wadi Zarqa or the sewer system could then become feasible through constructing evaporation ponds for the smaller volumes of blowdown.

Another feature has been added to help with pre-feasibility thinking. Supplying reclaimed water in bulk can be an inexpensive way to gain experience, educate the public, and displace some uses of potable water. While many issues would have to be addressed, a workable and safe bulk program would help pave the way toward increasing use of reclaimed water in the Amman-Zarqa Basin.

Three other potential sources of reclaimed water in the basin are Jerash (east), Abu Nuseir, and Baq'a. In addition, new plants are planned for Jerash (west) and Zarqa. The Jordanian standards for BOD_5/TSS of 50-50 mg/l, and the 15 mg/l PO_4-P do not bode well for non-agricultural reuse options. The BOD_5 and TSS values are not indicative of full secondary treatment, and the high discharge TSS values suggest difficulties with filtration and lower disinfection effectiveness than when suspended solids are at 30 mg/l (or lower following filtration). The high phosphorous concentration suggests that these treatment plants cannot be used for recirculating cooling systems without phosphorous removal. Thus, the plants at Jerash (east) and Baq'a do not appear to have good prospects for non-agricultural reuse without further treatment. The projected effluent values for a new Jerash (west) plant and the anticipated future Abu Nuseir plant effluent quality indicate that, under the right circumstances, these facilities could be developed into water reclamation plants for non-agricultural reuse, other than cooling. Considerations regarding standard-setting and regulation, planning as well as design aspects are similar to those described above for As Samra.

There appear to be no legal restrictions for use of reclaimed water. However, as detailed in this report, it will be important to institute appropriate treatment, water quality and distribution system standards for all non-agricultural uses. These approaches will require teamwork and planning by MWI, probably in conjunction with the Ministry of Health, to develop appropriate regulatory mechanisms, particularly for uses that could involve incidental public contact.

The acceptability of a non-agricultural reuse program will depend on a number of driving factors. These factors include cost, and development of standards and appropriate oversight programs, which may vary with intended reuse applications. It is most cost effective to develop a program meeting the broadest number of uses possible. In this way, specialized needs by industrial reclaimed water users are met by further on-site treatment. Large industrial users should be viewed as partners in the planning process; their acceptance can be earned through their involvement in this way. Public acceptance can be gained by involving appropriate community leaders through an open planning and implementation process.

A number of further studies are recommended. These recommendations include sponsoring studies of concrete and soil compaction with reclaimed water. Studies (paper and pilot) at the power plant and oil refinery are recommended both for cooling and for completely substituting (or "exchanging") ground water extraction with reclaimed water.

Acknowledgments

This report was written by Barnes Bierck and Bashaar Ammary, with the support of Peter McCornick, Ramzi Sabella and Nisreen Haddadin.

Our colleagues in the Ministry of Water and Irrigation have been active partners in this work, and have exerted considerable efforts in contributing and validating the work. We would specifically like to acknowledge the valuable participation of Eng. Nazeer Abu Arqoob, Director Environment Directorate; Eng. Suzan Taha, Director MIS Directorate; Eng. Edward Qunqar, Director Water Resources Directorate; Eng. Rania Abdel Khaleq; Eng. Mohammed Mansour; and Eng. Yasser Nazzal.

The cooperation and efforts of Eng. Issa Dallal of the Jordan Petroleum Refinery and Eng. Emad Sulaiman of the Hussein Power Station were invaluable. Also the staff of the Water Authority of Jordan (WAJ), the Royal Scientific Society (RSS), and the others who worked with our team, greatly facilitated the work.

Finally, the support of the United States Agency for International Development (USAID) Mission in Jordan, and the Associates in Rural Development (ARD, Inc.) team, in Jordan and Vermont, is highly appreciated.

Contents

Tables

Figures

I. Introduction

This activity targeted developing a pre-feasibility analysis for non-agricultural reuse of water reclaimed at the new As Samra treatment facilities. The new plant will be completed by 2004 - 2005, and a comprehensive program is underway to optimize beneficial uses of this new water resource. Approaches for municipal and industrial reuse of the reclaimed water were explored as a component of this program.

One task was to complete a pre-feasibility level study of the "HZR (Hashemite-Zarqa-Rusefeih) option" for water reuse. The basic aim of this option is to set up a reclaimed water service zone in the region south of As Samra. Other tasks were to examine opportunities and mechanisms for using reclaimed water instead of groundwater, and to identify and characterize potential non-agricultural reuse options for reclaimed water from other treatment plants in the Amman-Zarqa basin.

Work begun in June 2000 included considering features of civil works for providing reclaimed water to non-agricultural consumers in the HZR area. However, potential users of reclaimed water were examined only in broad terms. Further investigation was needed to determine whether there is justification for serving this region between As Samra and Amman.

During the activity reported here, interviews were conducted with representatives of the largest existing potential industrial users about their present and future needs, and their interest in using reclaimed water. Further, information was sought about a new, large residential and commercial area to be built in East Zarqa, which is also a potential candidate for reclaimed water. These and other steps taken and reported here are preliminary components of a detailed program for developing an effective, safe reclaimed water system serving non-agricultural interests.

The first step toward developing a viable reclaimed water system is to design and operate a water reclamation plant, not a wastewater treatment plant. The distinction is not insignificant, and it must be recognized that a water reclamation facility should be operated and maintained like a potable water plant (Okun, 2001). To have a realistic chance of developing a safe, effective water reuse program, virtually every aspect of the new As Samra facilities must be carefully thought out from this perspective.

Another feature has been added to help with pre-feasibility thinking. Supplying reclaimed water in bulk form can be an inexpensive way to gain experience, educate the public, and displace some uses of potable water. While many issues would have to be addressed, a workable and safe bulk program would help pave the way toward increasing use of reclaimed water in the Amman-Zarqa Basin.

II. As-Samra Treatment Facilities

Most aspects of the new As-Samra plant must bear scrutiny before, during and after planning for reuse. It is important that the facility be called a "water reclamation plant," <u>not</u> a "wastewater treatment plant." Use of the word "water" is reflective of conditions that must prevail: such a facility should be operated and maintained like a well-run potable water plant (personal communication, Okun, 2001). This approach includes meeting strict requirements for system redundancies and back-up, skilled and dedicated staff, a vigorous and ongoing employee training program, rigorous oversight and enforcement, and a clean and well-maintained working environment that cannot be allowed to deteriorate. Any decline in maintenance, operations, or appearance will destroy a non-agricultural reuse program.

Design components bearing on system reliability include appropriate redundancies in treatment processes (multiple treatment trains), stand-by equipment, storage of sufficient volume in case of upset, and appropriate monitoring equipment and procedures. The plant should be sustainable, which implies in Jordan a plant depending more on labor and less on automatic controls than for a more industrialized country where spare parts and specialized repair personnel are readily available. In turn, employees must be highly qualified and motivated, and be provided appropriate training and oversight.

Discharge requirements for the new As Samra wastewater treatment plant were discussed by Harza, et al. (1997). The standards include the following: 50 mg/l BOD5, 200 mg/l COD, 2000 mg/l TDS, 50 mg/l TSS, 25 mg/l NO_3-N, 15 mg/l NH_4-N, 50 mg/l Total-N, 15 mg/l PO_4-P, 350 mg/l Cl, and 230 mg/l Na, fecal coliform levels less than 1000 MPN/100, and Nematode eggs less than 1/liter. More recently, however, it has been indicated (MWI/ARD, 2001a) that these discharge limits have been tightened to TSS and BOD limits of 30 mg/l each. The recommended first phase (Harza, et al., 1997) was for a 267,000 m^3/d (97.4 MCM/yr) plant designed to meet these limits. While other plant design requirements are not available as of this writing, it can be assumed that the basic system will be secondary treatment.

Projected levels of other water quality parameters were summarized in MWI/ARD (2001a). Plans for future water supplies for the Amman-Zarqa basin suggest that concentrations of many important constituents will decrease as these sources come on-line. Potable water resulting from the Disi deep-aquifer project and from a new reverse osmosis project adding 45 MCM per year, among others, have lower TDS, hardness, and alkalinity values than the net resulting from use and discharge of existing potable water supplies. In addition, discharge and pretreatment regulations are under review, and preventing discharges of large volumes of reverse osmosis reject and ion exchange brines is under consideration. These factors should impact very positively on reuse options (for example, by reducing expense of further treatment for industrial purposes).

Further, if the waste stabilization ponds are not used for polishing, evaporation volumes will decrease, further reducing the concentrations of many constituents in the reclaimed water. The reuse planning process discussed below should include providing potential reclaimed water consumers detailed information on existing and projected water quality, and accompanying factors impacting on the projections.

For the present, it will only be possible to predict ranges for water quality parameters following treatment at the new water reclamation facilities. For example, effects of nitrification/denitrification on reclaimed water alkalinity will vary depending on design and operating conditions.

Water reclamation for non-agricultural uses is a relatively new concept. Based on experience elsewhere, the process of developing an industrial and municipal reclaimed water program can be broken down into a series of steps. Nevertheless, it is important for the appropriate regulatory groups, potential consumers, and other members of the community to work together to formulate a planning framework addressing local conditions and requirements. Such a framework should allow flexibility as knowledge is gained about various concerns and options are honed down through the necessary interactions. Elements of approaches for developing a non-agricultural reuse program are discussed in the next section.

III. Planning a Non-Agricultural Water Reuse Program

Irrigation aspects of water reuse are widely appreciated because agriculture is by far the largest sector consuming reclaimed water. For this and other reasons, there has been little opportunity in Jordan for considering non-agricultural approaches. Wastewater treatment facilities at As Samra, serving Jordan's largest population center, were overloaded practically from start-up. Population growth in the service area has been rapid, with accompanying increases in wastewater flows and expansion of the collection system. Now, plans for a new treatment plant at As Samra creates opportunity for considering the workings of a non-agricultural reclaimed water program.

Many government staff are involved with agricultural reuse planning. It is not unreasonable to suggest that an appropriate working group representing the appropriate engineering and scientific disciplines be assigned and focus effort on non-agricultural reuse.

Planning approaches applicable to non-agricultural water reuse have been detailed in various references, including US EPA (1992) and Asano (1998). A logical but flexible sequence should be developed by the appropriate decision-makers and stakeholders. The process begins with clarifying and agreeing upon the goals and objectives of a non-agricultural reuse program, and approaches for addressing all anticipated concerns.

This report includes a pre-feasibility level evaluation of technical and financial aspects of providing potential industrial and municipal users in the Amman-Zarqa basin with reclaimed water. However, as discussed above, the planning process must be further developed and carried out by the relevant parties. Approaches outlined in this report and references cited above can be used as a "jumping-off" point.

Enlisting reclaimed water consumers is of course very important for assuring that a reuse program will succeed. Market development during initial planning can make use of interviews for learning about existing and future water requirements, and consumer concerns. As concerns are learned, approaches for addressing them can be thought out and return visits conducted. Concerns by many potential users can be addressed by parallel activity developing draft standards and oversight programs, seeking input from relevant parties as necessary, earning their trust.

Potential users of reclaimed water will need a good deal of information during this planning process. Reuse planning efforts should include developing a policy of publishing all results of projected and actual reclaimed water quality analyses. These policies of openness help instill confidence in potential consumers.

Different levels of commitment to using reclaimed water are possible, and program planners and decision-makers must decide what level of commitment is acceptable in each case. An industrial user may ask for a contract, with guarantees as to quantity and quality; or use of reclaimed water could be mandated. User contracts may be difficult to work out except, for example, in cases where a reclamation facility is built directly in conjunction with a large industrial user(s). On the other end of the scale, a potential user might verbally indicate interest in using reclaimed water if a source is provided nearby. It does not seem reasonable to mandate use of reclaimed water by non-agricultural users in Jordan. However, economic development ultimately may depend on their cooperation. The best case now in Jordan may fall somewhere in between a contract and a verbal accord, possibly a written agreement worked out among the parties. Regardless, the best way to ensure that reclaimed water will be used by industrial users is by making them partners in the planning process.

Along with developing a start-up customer base, it is important to consider future growth in designing the civil works. These and other details of a reclaimed water transmission and distribution system are similar to those of potable water systems.

Municipal codes for reclaimed water transmission and distribution systems must be added to existing ones for potable water. Example codes are available from many sources, and can be modified to meet local conditions. Among other factors, the code should include regulations concerning signs, piping colors (the international standard is Pantone Purple 522C), rigorous requirements for preventing cross-connections, backflow prevention, and basic service approval and inspection procedures.

Market development was initiated during this activity by conducting preliminary discussions and surveying the largest potential industrial users of reclaimed water near As Samra. In addition information was gathered on a new municipal expansion plan in East Zarqa. Usually, the best initial customers are large users near a reclamation plant, minimizing distribution system costs. It is intriguing to note, as discussed in following sections, that such appears to be the case in the Amman-Zarqa basin.

IV. Cooling Water Applications for Water Reuse in the Amman-Zarqa Basin

Industries use water for a wide range of applications. The most water consuming applications are cooling, process water and boiler feed water. In order to reduce cooling water requirements, more industries around the world are now using cooling water systems that reuse water for cooling more than once. In addition, reclaimed water has been used for cooling in a number of industries to substitute or to supplement fresh water sources. In fact, industrial cooling is the largest non-agricultural water reuse application. A number of facilities use secondary effluent for cooling without further treatment (except for chemical additives to prevent scaling, fouling, and microbial growth). Others have extensive on-site storage and treatment facilities treating reclaimed water cooling and process use.

As cooling water for different industries can largely be considered independent of the type of industry involved, it can be viewed as a single process with its own water quality requirements. In this section, the potential of using the planned As-Samra treatment plant effluent for cooling is investigated. The technical feasibility of using this water, along with the costs estimated for the necessary treatment, in various types of cooling water systems are considered. These systems include once-through systems and recirculating cooling systems, especially cooling towers. Regardless of cooling system type, discharges are industrial wastewater, and must be regulated and monitored accordingly.

The applicability of using As-Samra effluent in the Jordan Petroleum Company, and the 99 MW Hussein Electric Power Plant, as examples, is shown. This is because these plants are the major water users for cooling purposes in Hashemite-Zarqa-Rusefeih area. These two large facilities near As Samra, presently use well water of relatively poor and decreasing quality for cooling and other process uses. In addition, a new 450 MW power station may be constructed near the water reclamation facility. It is reported that this new power plant will have no option but to use reclaimed water for cooling (MEM, 2001). These facilities could help form the basis for the HZR option service zone. Aspects of these facilities and possibilities for their using reclaimed water are discussed in the following sections. A comparison between their present cooling water supplies and the projected As-Samra effluent is also shown.

IV.1. Use of As-Samra Effluent in Once-through Cooling Systems

Once-through cooling systems require very large volumes of cooling water. This makes the use of reclaimed water from As-Samra in these systems impractical. More details about once through cooling systems, and the problems that may occur in cooling systems using reclaimed water are shown in Appendix A.

IV.2. Use of As-Samra Effluent in Recirculating Cooling Systems

Recirculating cooling systems are used to get the temperature of the cooling water down after it has been used to cool process equipment. The purpose of the cooling process in the cooling tower is to reduce water temperature to a point where it can be reused again to cool those same process equipment. They achieve that through evaporating part of the heated water to cool the rest before it is recirclated additional cooling cycles. The evaporation occurs either in a cooling tower or in a pond. Recirculating cooling systems can be designed for high recirculation ratios (up to five or six are most common). These systems require make-up water of higher quality, appropriate materials of construction, and chemical additives prevent scaling, fouling and microbial growth. Recirculating cooling system have been used in different industries such as oil refineries, electric power plant, metal manufacturing and others. Jordan Petroleum Company, and Hussein Electric Power Plant use cooling towers in their recirculating cooling systems.

When using reclaimed water for cooling tower makeup a number of points should be bear in mind. Wind dispersal at the top of the tower causes water to escape as mist, in what is known as drift. This water should not come into contact with workers, unless it is well disinfected. Mist and drift eliminators may have to be added, but they will not be able to eliminate them completely. Drift is usually not a problem in cooling ponds, however. In cooling ponds water evaporates from the pond surface area, cooling the recirculated water. For new plants using As-Samra effluent in recirculating cooling systems, cooling ponds should be considered. The advantages of using cooling ponds over cooling towers is that they have a lower capital cost and a larger storage capacity which is necessary in case of an interruption of As-Samra effluent. On the other hand, algae and weeds growth, large land area requirements, and groundwater contamination potential are serious disadvantages.

Another point of concern is the concentration of contaminants in recirculating cooling systems as a result of evaporation. To limit this increase in contaminants concentration to an acceptable point, part of the cooling water is discharged (blowdown) and replaced by fresh reclaimed water (makeup). The ratio of the concentrations of salts in the blowdown water to those concentrations in the makeup water is called the concentration ratio or the cycles of concentration (COC). Recirculating cooling systems usually are operated in the 5 to 10 cycles of concentration range.

At the present time, the oil refinery and the power plant are using groundwater for cooling with two cycles of concentration. If reclaimed water from As-Samra substitutes the groundwater, the quantity of cooling water required would become mainly dependent on the cycles of concentration. If only blowdown and evaporation losses are considered, the COC is also equal to the ratio of makeup to blowdown flow rates.

If recirculation of the projected As-Samra effluent is to be practiced in the cooling water systems without pretreatment, the formation of calcium phosphate scale is expected. A number of treatment processes can be used to reduce phosphate and calcium concentrations. These processes are discussed in this section.

Table 1 shows the maximum general quality requirements for makeup water for 5 cycles of concentration (COC) (Metcalf and Eddy 1991, MOP SM-3). The projected As-Samra effluent quality parameters are also shown for comparison. The table shows also the number of COC that can be used with As-Samra effluent in circulating cooling water systems before the concentration of each parameter reaches the concentration of the maximum general quality requirements for circulating water after 5 COC.

Table 1. Comparison between maximum general quality requirements for makeup water for 5 cycles of concentration.

Constituent	Makeup Maximum Concentration (mg/l)	Projected As-Samra (mg/l)	Allowed As-Samra effluent COC*
TDS	500	1220	2.0
Suspended Solids	100	30	16.7
COD	75	200	1.9
Ammonia (NH_3-N)	1.0**	15	***
Phosphorous (P)	1.0	15	***
Hardness ($CaCO_3$)	650	485	6.7
Alkalinity ($CaCO_3$)	350	425	****
Calcium	50.0	95	2.6
Bicarbonate	24.0	520	****
Chloride	500	350	7.1
MBAS	1.0	20	***
Iron	0.5	0.19	13
Aluminum	0.1	0.3	1.7
Manganese	0.5	0.09	27
Silica (SiO_2)	50	-	-
Sulfate	200	26	38

* calculated by multiplying makeup water requirements for 5 cycles of concentration (COC) (column 2) by 5 and dividing by As-Samra effluent (column 3).
** has never been a problem at concentrations encountered (Metcalf and Eddy 1991, Goldstein and Casana 1982). Golstein and Casana 1982 reported a problem (corrosive) at concentrations greater than 300 – 400 mg/l nitrate at pH 6.0 – 6.4
*** initial values are already higher than the cooling water concentration (makeup water concentration multiplied by 5).
**** do not concentrate by the same factor as other constituents.

Table 1 shows that three parameters can limit the use of As-Samra effluent in recirculating cooling systems. These parameters are ammonia, phosphorous, and MBAS. The concentrations of these parameters are initially higher than the recommended maximum general quality parameters for 5 cycles of concentration. Other than that, the As-Samra water can be used for about 2 cycles of concentration.

The problems that ammonia can cause are biofouling enhancement, chlorine consumption, and corrosion. Corrosion occurs as a result of ammonia changing to nitrate and then to nitric acid. However, ammonia has seldom been a problem at concentrations encountered (Metcalf and Eddy, 1991; and Goldstein and Casana, 1982). Goldstein and Casana (1982) reported a problem (corrosion) at concentrations greater than 300 – 400 mg/l nitrate at pH 6.0 – 6.4. With the As-Samra effluent having this high alkalinity, the presence of ammonia may even be beneficial if nitrification occurs in the cooling system. This reduces the alkalinity of water and thus reduces chemicals dosages like lime and carbon dioxide when pH changes are required. Higher chlorine dosage may, however be necessary.

High MBAS concentrations in As-Samra effluent can cause foaming problems. If foaming continues to be a problem, then flotation may have to be used to reduce it.

Measures could be taken at the new As-Samra plant to reduce foaming problems. These could include aeration of grit chamber and skimming. MBAS concentrations in five mechanical treatment plants (Abu Nuseir, Irbid, Salt, Kufranjeh, and Jerash east) effluents range from 0.5 to 5.3 mg/l (RSS, 1996) much less than the projected As-samra effluent. Therefore, the MBAS concentration in the new As-Samra plant may be lower than the present or the projected values. This potential problem should be taken into consideration in the design of the new As-Samra plant.

The high concentration of phosphorous in As-Samra effluent is the main constituent that could limit the use of the projected As-Samra effluent in recirculating cooling systems. Jordan's wastewater is strong due to the low per capita consumption. This results in high phosphorous concentration, along with other constituents, such as BOD. Phosphorous, however is only slightly removed by conventional secondary treatment. Phosphorous concentration has to be reduced before being used in recirculating cooling systems, as the formation of calcium phosphate deposits are costly to remove and therefore must be prevented.

IV.2.1. Phosphorous Removal

Industries requiring water for cooling purposes may either receive water with a quality directly suitable for recirculating cooling systems, or they may have to treat it themselves. In the former option, the treatment cost will be reflected in the water cost. Phosphorous removal from As-Samra effluent is necessary before it can be used in recirculating cooling systems. The degree of treatment determines the cycles of concentration possible and therefore the quantity of water required. It also determines the quantity and quality of blowdown, especially TDS. Phosphorous removal may either be achieved at As-Samra treatment plant, or at the industry site. Different treatment options are possible and are discussed in this section.

For low cycles of concentration (less than 2), an extensive treatment for phosphorous removal is not necessary. Low lime treatment can be used to reduce phosphorous concentration either at the industry site or at As-Samra treatment plant.

Low lime treatment can be used either before primary clarification or after secondary treatment. The addition of lime before primary clarification has the advantage that no substantial additional capital cost investment is necessary. A separate train in the As-Samra plant should be, however, dedicated for phosphorous removal. This train should be able to handle only the volume of water required by the industry for cooling. Lime is added into a flocculation tank before primary clarification to get the wastewater pH to approximately 9.0. The wastewater then passes through the usual secondary treatment process. The secondary treatment process should be carefully monitored as lime addition may adversely affect it.

This treatment process typically reduces the phosphorous concentration to about 2 to 3 mg/l (WEF MOP No. 8,1998). The lime dosage required is not dependant on phosphorous concentration. The factor that determines lime dosage is alkalinity. As alkalinity increases, the lime dosage required to reach a specific pH value increases. A dosage of about 200 mg/l lime is usually required for water having alkalinity about 400 mg/l as $CaCO_3$. Lime addition before primary clarifiers requires a rapid mixing step followed by a flocculation tank. Loading and unloading facilities along with mixing and dosing facilities for lime are necessary. In addition to phosphorous removal, lime addition improves the primary clarifier efficiency, and heavy metals removal. The use of low lime treatment, however, produces about two times the volume of sludge produced by traditional treatment. Cost estimate for this option is included in Table 3 in the HZR option section.

The advantage of this treatment train is reduced capital cost. The available primary sedimentation basins are used. On the other hand, the efficiency of this process is lower than other processes for phosphorous removal used after secondary treatment. Lime is more effective in orthophosphate precipitation than other forms of phosphorous. For raw wastewater, the portion of orthophosphate is lower than that after secondary treatment, where most of the phosphorous present is in the orthophosphate form. In addition, phosphorous is required in the biological treatment of wastewater. Reduction of phosphorous to values lower than that required by bacteria can upset the secondary treatment process. The minimum phosphorous to BOD_5 ratio requirement for aerobic biological treatment is 1:100 (WEF MOP No. 8, 1998). For an influent BOD_5 of 600 - 700 mg/l entering the As-Samra wastewater treatment plant, and assuming a 30 % BOD removal in the primary sedimentation tank, the minimum required phosphorus concentration is around 4 – 5 mg/l. The removal efficiency may be higher than 30% in case lime is used, and 3 mg/l phosphorous may be adequate for effective secondary treatment.

Lime can also be used for phosphorous removal after secondary treatment. Either single stage or two-stage lime treatment (high lime treatment) can be used. Single stage lime treatment is essentially similar to lime addition before primary sedimentation, except that here a clarifier is required. The advantages of adding lime after secondary treatment, however, are that the removal efficiency is higher, and no adverse effect on the secondary treatment is realized. In the two-stage lime treatment, the pH of the water is controlled around 11 or more in the first clarification stage. In the second clarification stage, the pH is reduced to around 9-10 by carbon dioxide, thus calcium carbonate precipitates. The advantage of two stage lime treatment is that calcium, magnesium, silica, and suspended solids are removed in addition to phosphorous removal.

Table 4 (in HRZ option section) shows the cost estimate for a two-stage lime treatment train of As-Samra effluent receiving secondary treatment, and followed by filtration. The cost estimate is for a 450 mg/l lime dosage.

It is important to note that the cost estimate shown in Table 3 is for an annual flow of 13 MCM. The quality of water produced by this treatment is higher than the quality of the other alternatives, as this treatment reduces scale forming constituents (calcium, magnesium, silica, and phosphorous). This allows for more cycles of concentration, and therefore lower cooling water requirements. This type of treatment can reduce the concentration of phosphate to less than 1 mg/l (less than 0.5 mg/l phosphorous), and calcium to less than 20 mg/l. The quality of water produced would allow for at least 5 cycles of concentration, if only scale forming constituents are taken into consideration. For the oil refinery, as an example, if 5 cycles of concentration is achieved, then the water required would be around two thirds of what is required for the present two cycles of concentration. The amount of blowdown would be around one fourth of the present discharge. This would then allow for lower construction requirements and lower chemical cost requirements. Lower blowdown discharge is very important because it makes the evaporation of this lower amount in evaporation ponds more economically feasible. Zero discharge option of cooling water blowdown would then become possible.

Alum or ferric salt coagulants can also be used to remove phosphorous from wastewater, either before primary sedimentation or after secondary treatment. The advantage of using these coagulants is lower sludge volume. Theoretical Alum, and ferric chloride dosages required for phosphorous removal are 10 and 5 mg per 1 mg of phosphorous, respectively. Higher dosages are usually required in practice, as a result of the competing reaction with alkalinity, and these figures may double (Schimmoller et al., 2000).

For the projected As-Samra effluent, the high phosphorous concentration makes the alum or ferric salts dosages required quite high. Alum dosage required for effective removal of phosphorous may range between 150 and 300 mg/l. The high dosage required by these coagulants makes the chemicals cost quite high. For the 13 MCM per year, the required alum quantity would be around 3000 tons (for a 225 mg/l dosage) with a cost of around 2.5 million JD per year. This high chemical cost makes it unfeasible to use alum or ferric coagulants for phosphorous removal. In addition, alum does not reduce the concentration of calcium and magnesium, and therefore, the cycles of concentration using alum are expected to be less than the cycles of concentration when two-stage lime treatment is used.

Alum can also be added to the aeration tank. This alternative does not require the addition of any rapid mixing or flocculation tanks. Mixing occurs in the aeration tank. This alternative requires the presence of high alkalinity in the treated water to allow for effective biological treatment, as high dosages of alum consumes alkalinity. The projected As-Samra effluent is to have high alkalinity (425 mg/l as $CaCO_3$), and therefore, this option is technically feasible. Chemical Cost is also high, as here most of the available phosphorous is in the form other than orthophosphate which is harder to remove than orthphosphorous.

In the following section, the possibility for the oil refinery and the power plants to use As-Samra reclaimed water after treatment for phosphorous removal is discussed.

IV.3. Potential Candidates for Reclaimed Water Use in Cooling

IV.3.1. Jordan Petroleum Refinery

The Jordan Petroleum Refinery refines crude oil and blends lubricating oils. Ground water pumping by the refinery is significant: current usage is 240 m^3/hr (2.1 MCM/yr), 0.6 MCM/yr of which is used for make-up water fed to two cooling towers. The refinery pays 0.25 JD/m^3 of well water for a total annual cost of about 547,500 JD. (Pumping and water treatment costs are not included in this figure.) Future water demand is expected to increase to 450 m^3/hr (3.9 MCM per year) as the facility expands.

Refinery well water quality is poor, with TDS values at about 2500 mg/l and increasing. Reverse osmosis and ion exchange systems are in place to produce water for process use. Changes in chemical additives recently were made, allowing cooling tower recirculation ratios of about 1.5 to 2. Inspection of the cooling towers indicated wind-blown mist contacting plant personnel.

During an on-site interview, refinery management discussed factors regarding possibly using reclaimed water. Primary concerns are reliability and cost. While there were some concerns about ammonium and organic content, refinery technical staff indicated that they would discuss use of reclaimed water with their chemical additive supplier. They noted further that reclaimed water should meet certain specifications and the reliability of the As Samra reclamation plant will have to be proven before there could be real interest in using reclaimed water. Further, refinery management indicated great interest in being involved in discussions at the highest levels about water reclamation at the As Samra plant.

IV.3.2. Electric Power Station

The electric power station is a 99 MW plant operating at full capacity, 24 hours per day. The power station uses groundwater with high and increasing TDS values (about 1800 mg/l). The station has two basic cooling systems, an air cooled system for 66 MW and an open cooling system (4 small cooling towers) for the remaining 33 MW of generating capacity. The facility has done much to reduce well withdrawals, from 130 m^3/hr in 1996 to 62 m^3/hr in 2000 through use of internal recycling measures. Of the 62 m^3/hr, about 8 m^3/hr is used for cooling tower make-up and 42 m^3/hr is treated by reverse osmosis for process uses, including boilers and fuel atomization.

Discussions were held at the power station about possibly replacing the 8 m^3/hr of make-up water with As Samra water. However, this flow rate is a small one, and plant management suggested thinking about other approaches such as using a heat exchanger. In summer the closed cooling system operates at temperatures up to 45 - 55 deg C, resulting in a relatively low efficiency of about 30%, as compared to the power station at Aqaba which uses cooling water directly from the Red Sea (36% efficiency). The plant's summer efficiency could be improved by replacing air cooling with a heat exchanger tied to a cooling tower using As Samra effluent. Operating costs savings could arise from such modifications. However, full understanding of the benefits of this and other approaches would have to be determined by more detailed studies.

Note has been made of a new electric power station to be built near the As Samra reclamation plant. It is reported that an agreement will be made between the private concern (a Belgian firm) that will run the power plant and WAJ to supply reclaimed water from the As Samra plant. There apparently will be no other source of water for the plant; wells will not be permitted. As reported, WAJ will be paid for this flow at a rate which will increase as the quality of supplied water increases. (Current rates in Jordan are about 50 fils/m^3 for such supplies.) The agreement will include a guarantee of 630 m^3/hr (5.5 MCM/yr if the facility operates 24 hours a day). Details about reuse by this power station are lacking. There apparently will not be guarantees of water quality and it has been noted that the power station will be responsible for transmission facilities and other civil works associated with using reclaimed water from the new As Samra facilities.

Comparison of the projected As-Samra effluent, and the presently used groundwater by the oil refinery and the power plant is shown in Appendix B. Water quality data for different plants around the world using reclaimed water for cooling is also shown.

Municipal uses of reclaimed water are another option for the Amman-Zarqa basin. These uses include irrigation of ornamental plantings along roads and park areas; fire protection; and for toilets and urinals and air conditioning large commercial and public buildings. A large, new urban area is being planned in East Zarqa. While distribution to residential units does not appear warranted, a grid system serving this area could displace some uses of potable water, and permit construction of park areas that might otherwise not be considered. These and other municipal uses would involve constructing a dual water distribution system as discussed in the next section.

V. Dual Water Distribution Systems

Dual water distribution merits consideration when new areas are being developed, such as the new urban East Zarqa Development area (at the site of a former military camp). These systems are much less expensive to install with other services than by retrofitting. The population growth rate of Jordan is high (about 3% per year), and construction is rapid--the East Zarqa Development area will house up to 450,000 people over the next fifteen years. Services, including roads, water transmission, and wastewater collection systems are being laid out for the first 40,000 persons there.

Non-potable water distributed in this manner can serve many purposes, and helps conserve high quality sources for potable use. Possible public applications in Jordan include irrigation of park areas and amenity gardens, landscaping along roadways, firefighting, toilet and urinal flushing in large commercial and public buildings, recreational areas, for the urban horticulture industry, and clean-out of wastewater collection systems. Commercial air conditioning units can use reclaimed water as well if it is of suitable quality. (If not, additional treatment can be added at the point of use.) Most of these uses involve the possibility of incidental public contact, and need to be carefully considered in view of above-mentioned requirements for reliability and appropriate standards and regulation.

A number of factors unique to Jordan influence the feasibility and types of dual distribution systems appropriate for urban areas. These factors include water consumption, public acceptance, and need for standards for unrestricted public reuse. Harza, et al. (1997) noted that the (adjusted) water consumption in the Amman-Zarqa basin is about 115 liters/capita /d. This relatively low consumption rate is reflective of local conditions, including low volumes for toilet and urinal flushing, potable water expense, and the manner and frequency of delivery (intermittently, whether weekly through the distribution system or by green tanker truck delivery). For these reasons, supplying reclaimed water to residential buildings does not appear appropriate in Jordan at present. However, residential use considerations are separate from other possible public and commercial applications of a dual system.

Systems for distributing non-potable water for these purposes can be constructed by conventional methods to beautify and make more pleasant living in highly urbanized areas such as Zarqa, while serving other public and commercial uses. These uses could result in incidental public contact, requiring appropriate standards as discussed in the next section.

VI. Standards for Unrestricted Urban Reuse

Standards for unrestricted urban reuse must be developed, addressing water treatment and quality, system reliability, and system construction requirements. The US EPA (1994) guidelines include the parameters listed in Table 2 for uses that could result in public contact. These guidelines add that no pathogens should be detectable in the reclaimed water, and that it should be clear, odorless, and not contain substances that could be toxic upon ingestion.

Proposed modifications (MWI/ARD, 2001b) to Jordanian standard 893 do not address specifically the case of urban reuse with potential for public contact. However, the proposed standard bearing most closely on this option, "Irrigation for Public Parks," should suffice. This suggested standard, which should address incidental public contact, recommends maximum values of BOD_5 of 30 mg/l, a maximum turbidity average of 2 NTU, 50 mg/l NO3-N, a chlorine residual of 0.5 mg/l and FC of 23 MPN/100 ml. Meeting consistently a turbidity level of 2 NTU will require filtration following secondary treatment at the new As Samra facilities. Reclaimed water after filtering would be expected to have TSS and BOD_5 values well below 30-30 mg/l.

Chlorine disinfection following filtration is much more effective when suspended solids levels are reduced by filtration. Therefore, adding requirements for filtration and a FC level of non-detectable appear to be reasonable modifications to the proposed public parks standard, for uses that could involve incidental public contact.

Disinfecting with chlorine to a level of 0.5 mg/l in the reclaimed water distribution system has significant benefit. Bacterial growth is minimized, while the reclaimed water is kept microbiologically safe. Unlike potable water systems, there are no problems associated with creation of low concentrations of disinfection byproducts. Rapid formation of chloramines keeps formation of chlorinated hydrocarbons to a minimum.

Table 2. Guidelines for reclaimed water for urban reuse US EPA (1994).

Treatment	Reclaimed Water Quality	Reclaimed Water Monitoring	Setback Distance[e]
Secondary, Tertiary Filtration[a], and Disinfection	pH 6 - 9 BOD_5 10 mg/l Turbidity, avg. 2 NTU max 5 NTU FC[b]: not detectable Residual chlorine: 1 mg/l[c,d]	pH - weekly BOD - weekly Turbidity - continuous Coliform - daily Residual Chlorine - continuous	15 m to potable water supply wells

[a]With filter aid (polyelectrolyte and/or coagulant)
[b]Fecal coliform
[c]After 30 minutes of contact time. Addition of chlorine both before and after filtration should be considered for reducing microbiological growth on filters while assuring an adequate chlorine residual in the storage and distribution systems.
[d]A minimum 0.5 mg/l concentration in the distribution system is recommended
[e]For irrigation

Storage requirements must also be considered for municipal (and industrial) reuse facilities. In general, storage systems should be designed to even out demand fluctuations occurring during the 24-hour day, provide for future growth, and take into account peak demand periods during the year. Design of civil works, including storage and transmission systems is similar to water distribution systems as noted above.

Standards for reclaimed water uses that could result in incidental public contact also apply to construction uses. These uses are discussed in the next section.

VII. Construction Uses of Reclaimed Water

Construction uses for reclaimed water include concrete mixes, sewer cleanout, and soil compaction. Ready-mixed concrete specifications refer to use of “Questionable Water Supplies” (ASTM C94/C 94M0, 2001). This specification notes that the water used should be “clear and apparently clean,” but that water not of this description can be deemed acceptable by meeting specified test requirements for compressive strength and setting time.

The ASTM ready-mixed concrete specification also permits use of wash water resulting from mixer clean-up operations, noting that various chemical admixtures should be adjusted according to experience, and providing optional chemical characteristics relevant to reclaimed water from As Samra. These characteristics include a maximum chloride level of 500 ppm (for prestressed concrete or for bridge decks) or 1000 ppm (for other types), and a maximum of 3,000 ppm sulfate a total solids level of 50,000 ppm. It has been reported that Jordanian concrete standards require use of high-quality potable water. Further investigation of use of reclaimed water in concrete mixes can include closer examination of all relevant standards, discussions with concrete suppliers and their chemists, and research.

Other uses of reclaimed water for construction merit further investigation. As with concrete mixes, adjusting the water content of soils for compaction can be studied further by examining standards, and conducting studies. Use for sewer-cleanout would not require research. However, this and other construction uses involve possibility of incidental human contact, requiring appropriate standards and controls.

VIII. Hashemite-Zarqa-Rusefeih (HZR) Option

The HZR option targets developing a reclaimed water service zone in the region south of the new As Samra treatment facilities. This area includes industries relatively close to the plant which use (or are planning to use) relatively large volumes of cooling water. In addition, new residential areas are planned in the East Zarqa area between As Samra and Amman. Under the right circumstances, such a situation can be ideal for developing a non-agricultural reclaimed water system.

As discussed above, the oil refinery and power plant currently use well water with high TDS values that are increasing with time. While the oil refinery and power plant use approximately 88 m^3/hr and 8 m^3/hr of well water, respectively, for cooling tower make-up, both facilities use much larger quantities of well water through use of on-site treatment systems. These facilities are prime candidates for using reclaimed water for make-up water now, and for their entire water needs in the future if additional water treatment facilities are added. This step would be a significant "exchange of use with" (or substitution for) ground water pumping.

A new 450 MW electric power facility helps drive industrial reuse considerations in the Amman-Zarqa basin. The plant was originally reported as requiring 15 MCM per year of reclaimed water for cooling. Recently, however, it was learned that it will require 630 m^3/hr (equivalent to 5.5 MCM per year if operated continuously). Nevertheless, this quantity is not insignificant.

These industrial cooling possibilities suggest that a reclaimed water system serving non-agricultural consumers is possible. The financial considerations indicate it is affordable. However, the success of such a project depends upon much effort by all concerned (policy-makers and regulators, those planning the new As Samra treatment facility, the industries themselves, and others as appropriate).

The East Zarqa planning area is slated to house 40,000 persons now, reaching 450,000 persons in 15 years. This area is a prime candidate for a dual water system. The relatively low volumes of residential water use in the basin indicate it will not be useful to provide non-potable water service to residential units. However, an abbreviated system serving commercial establishments (hotels, office buildings, ornamental horticulture, etc.), public buildings (government buildings, schools, etc.) and for public irrigation (of parks, roadways) and other public needs (such as sewer cleanout and fire fighting) may be feasible. However, as for industrial uses, success of such a system will hinge on many important factors. In addition, public health considerations become paramount when there is possibility of incidental public contact as is the case here.

A further HZR phase was considered, extending the transmission main southward to a former phosphate mining area. This area includes a large lagoon (formerly called the "Pepsi lagoon"), which could be a focal point for a new recreational area. However, nutrients in the reclaimed water will cause algae blooms and accompanying unsightly conditions. This factor and the distances involved (an additional 14 km), indicate it is more feasible to focus present planning efforts nearer As Samra where an initial customer base exists. Still, as detailed below, the system suggested for further consideration can be readily expanded to serve regions closer to Amman, including the former phosphate mining area.

The HZR option is detailed in Figures 1 and 2 and 3. Phosphorous removal is necessary to prevent the formation of scales in cooling systems. Two stage lime treatment removes in addition to phosphorous, other scale forming constituents. It also can have a role in the disinfection process as a result of the high pH encountered in these systems. Filtration is recommended for a number of reasons. Disinfection is more effective and chlorine residuals last longer when suspended solids are reduced. These factors are important for the oil refinery where aerosols were observed reaching plant employees. A system involving public uses and possibility of incidental public contact will require filtration. In addition, there are possibilities that the industrial users will substitute over time even greater quantities of well water with reclaimed water, provided additional treatment facilities are put in place at the industrial sites. Providing filtered, disinfected reclaimed water will lower financial barriers to taking this step.

Storage for reclaimed water will be important for industrial facilities. Site-specific factors, including systems for additional treatment will dictate storage needs. (Regardless, the existing power plant and oil refinery should maintain their wells for back-up.). Storage facilities may require covers to prevent growth of algae. Costs of storage at industrial sites and for connecting to the backbone system should receive further consideration during more detailed follow-up studies.

As shown in Figure 1, the system suggested for further consideration will have automatic turbidity and chlorine monitoring, connected to automatic valves preventing distribution of reclaimed water not meeting standards. (Recommended standards are discussed above.) Filter backwash and reclaimed water not meeting standards can be routed to either the discharge or the influent, allowing operational flexibility. Multiple chlorination points are shown; however, a single disinfection system (with appropriate redundancies) can feed to all these points simultaneously. (Breakpoint chlorination is not suggested here. Chemical costs for so doing would be tremendous, and unnecessary.)

The system shown in Figure 1, and indeed the entire new As Samra plant as it is currently understood, will be sophisticated. Design, operations and maintenance considerations are tied to discussions above that the entire treatment plant should be operated like a water treatment plant, and termed a water reclamation plant, <u>not</u> a wastewater plant.

DRAFT

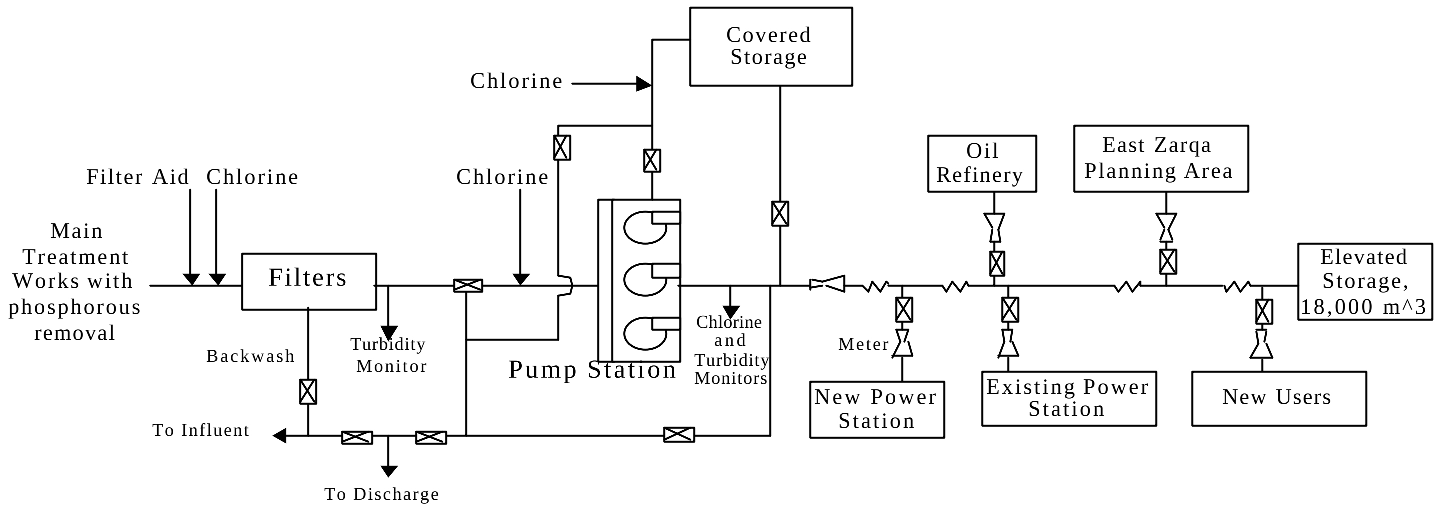
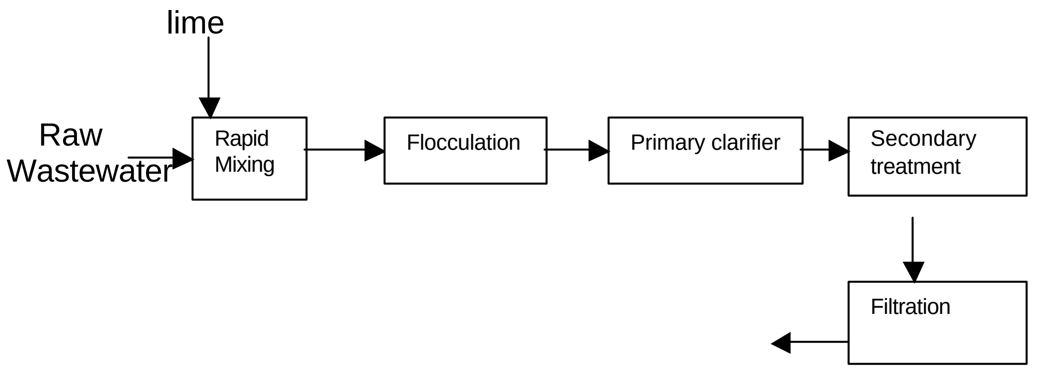
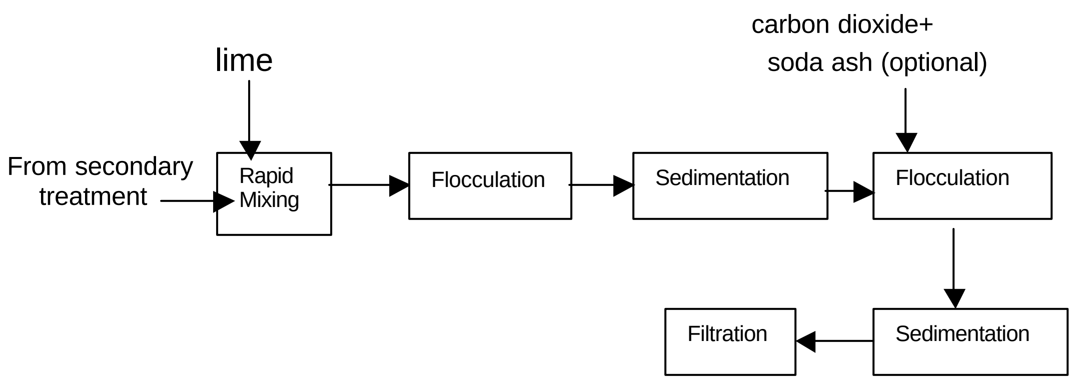


Figure 1. HZR Option: Treatment, Transmission and Storage.



(a)



(b)

Figure 2. Phosphorous Removal (a) Lime addition to primary clarifier. (b) Two stage lime treatment followed by filtration and disinfection).

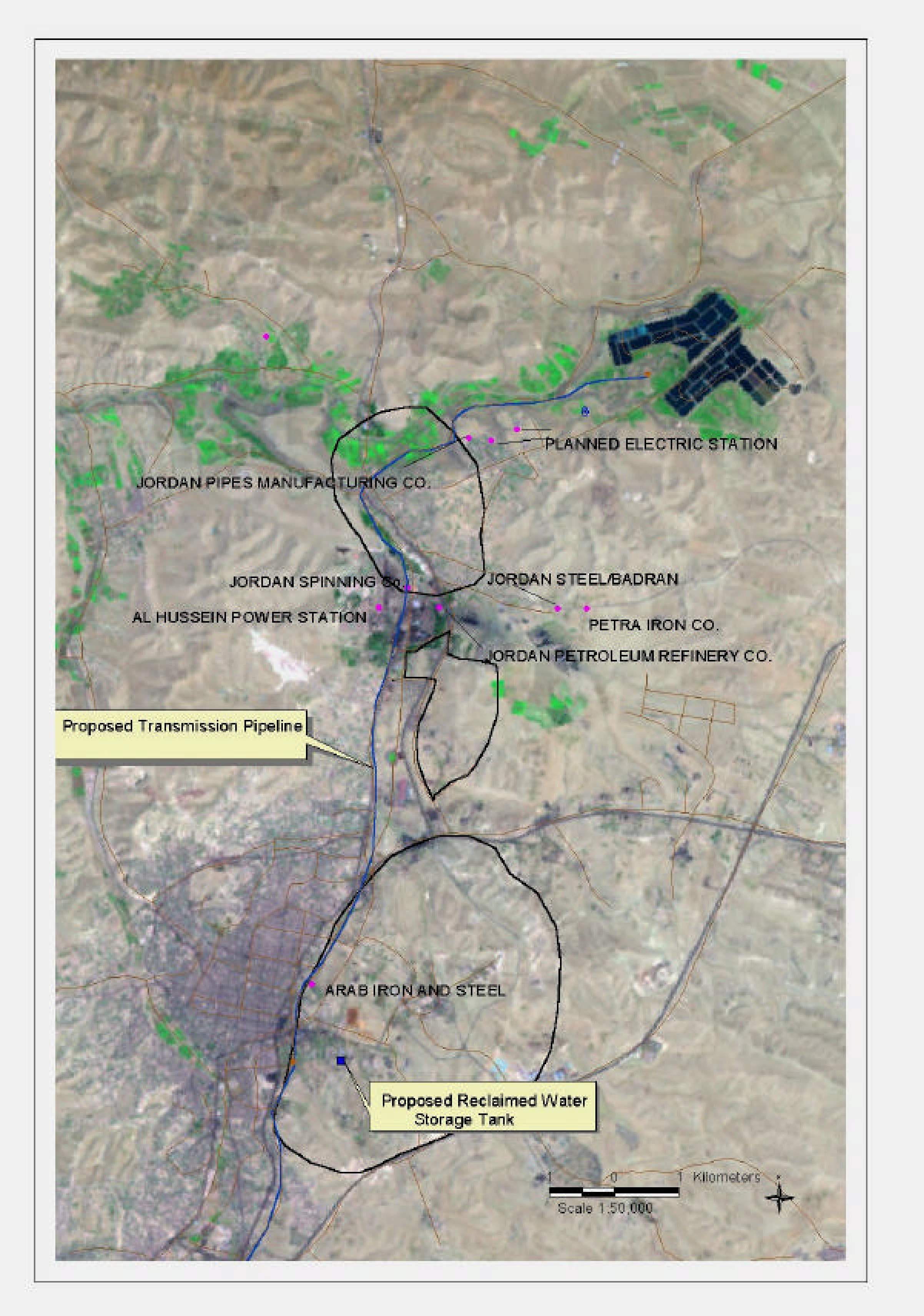


Figure 3. The HZR Option

On-site storage will be necessary at the treatment plant. It appears feasible to store up to a week (or more) of reclaimed water flows using one or more of the existing waste stabilization ponds. It will be important to cycle reclaimed water through the storage system to maintain it and prevent stagnant conditions.

Many reclamation facility components are not shown in Figure 1. These components include level monitors in storage systems, controls, most aspects of the filtration system (including back-up filtration capacity), meter vaults, transmission main details, back-up chlorination equipment and chlorine contactors, etc. These and other important factors regarding the facility (such as operations procedures) must be considered in detail as planning unfolds, involving all potential users of reclaimed water, regulators, policy-makers, and others as appropriate.

Based on preliminary evaluations, the predicted demand pattern of reclaimed water for this HZR option at As-Samra plant are shown in Table 3. Demand at start-up and increases over time will depend on a number of factors. As discussed above, successful sign-up will result from careful planning among all parties, possibly including pilot studies by industry. Future reclaimed water demand is predicted to increase: it is assumed that the oil refinery and power plant will install additional treatment facilities, making more use of reclaimed water over time, eliminating withdrawal from wells. It is assumed that the East Zarqa Planning Area will replace approximately 10% of its consumption (of about 120 L per capita per day) with reclaimed water.

Other, smaller industrial users near the distribution system shown in Figure 3 may also be connected, as indicated in Table 3, as planning continues. Such users include industries being courted by economic development groups. As shown below, this user base appears sufficient for assuring that the system will be affordable.

HZR system cost estimates are shown in Tables 4 and 5, including O&M costs and cost estimates per cubic meter of production[1]. Table 4 is the cost if primary clarifier low lime treatment for phosphorous removal is used, while Table 5 is for two stage tertiary lime treatment. Note that the cost per cubic meter depends upon the total amount sold because the loan payback per cubic meter decreases as more reclaimed water is sold. Thus, it is important to have a customer base lined up from the outset, for generating income to pay loan and O&M costs. At system start-up, the cost per cubic meter is estimated to be 0.248 and 0.345 JD, for phosphorous removal in the primary clarifier and tertiary lime treatment, respectively. When 13 MCM per year are sold, the cost is predicted to decrease to 0.157 and 0.232 JD per cubic meter, respectively.

Cost estimates must be honed as the planning process unfolds. System hydraulic needs (including exact pipe sizes and optimal storage tank sizes) will vary depending

[1] Note, due to the expected additional costs of phosphorous removal, the costs presented here are higher than those generated in the earlier draft of this report, which were 0.20 and 0.12 JD/m^3 for 6 and 13 MCM cubic meters sold per year respectively. These increased costs do not affect the economic analysis presented in Shaner (2001), which used the earlier numbers, not do they affect the final prioritization of options presented in the water reuse plan (MWI/ARD, 2001c).

upon the precise locations of reclaimed water users, water velocity requirements, and the like. One basic principle is that system pumping and transmission capacity should be designed to initially provide a full day's demand over a maximum of about eight hours. This approach permits meeting demand growth simply by operating more hours per day.

Table 3. HZR Option Possible Start-Up and Future Reclaimed Water Flow Scenarios.

Reclaimed Water User	Demand at Start-up, MCM/year	Future Demand, MCM/year
Oil Refinery	0.60	3.9
Power Plant	--	0.61
New Power Plant	5.5	5.5
Other Industry	0.3	1.0
East Zarqa Planning Area	0.18	1.97
Total	**6.6**	**13.0**

Cost estimates for the two alternatives of phosphorous removal should not be compared without considering the quality of water produced. The two-stage tertiary lime treatment produces water with lower concentrations of phosphorous, calcium, magnesium, and silica. This may allow for higher cycles of concentration in the cooling systems, which means lower volumes of water required for cooling. Therefore, it is necessary to conduct a pilot study to investigate whether the extra investment in the two-stage lime treatment is economically warranted.

After phosphorous removal, the quality of water will be suitable for circulating cooling water systems without further treatment at the industrial sites. This is expected to have lower cost than having a number of phosphorous removal plants at each industrial site. This is applicable since a large portion of the required water by the three major water users near As-Samra is for cooling purposes. In addition, the quality of water required for other high consuming processes, such as boiler feed water benefit from such treatment. Additional treatment is necessary, however, since these processes require lower concentrations of the scale forming constituents.

Table 4. HZR cost estimate with primary clarifier low lime treatment phosphorous removal.

Item		Capital Cost, JD
Rapid Mixing Basins		330,000
Flocculators		1,300,000
Filtration Facilities (for 13 MCM, expandable)		2,400,000
Pump Station, civil works		220,000
Pumps (4 x 150 HP each)		220,000
Meters, valves, air release valves		150,000
Storage Reservoir (18,000 cubic meters)		2,400,000
Backup Chlorination system		220,000
Yard piping		200,000
	Subtotal	7,440,000
Electrical (10%)		744,000
	Subtotal	8,184,000
Contractor OH and Profit (25%)		2,046,000
	Subtotal	10,230,000
Contingencies (10%)		1,023,000
	Subtotal	11,253,000
Transmission main to external storage tank		
	17 km of 600 mm DI pipe at 150 JD/m	2,550,000
	Subtotal	13,803,000
Design, Engineering (7%)		966,210
Land Acquisition		120,000
	TOTAL	14,889,210
Debt Retirement Factor (6.5%, 25 years)		0.0819
Annual Cost of Capital		1,219,426
Estimated Annual Component of Cap Cost (JD per cubic meter) at startup (6.6 MCM)		0.185
Estimated Annual Component of Cap Cost (JD per cubic meter) at future capacity (13 MCM)		0.094
Annual O&M		
Labor	Start-up (12 hrs/day)	80,000
Labor	Future (24 hrs/day)	160,000
Chemicals (lime, chlorine and filter aid)		
	Start-up (12 hrs/day)	200,000
	Future 24 hrs/day	400,000
Power	Start-up 12 hrs/day	68,000
Power	Future 24 hrs/day	138,000
Sludge Handling	start up	70,000
Sludge Handling	future	140,000
O&M per year, start-up		418,000
O&M per year, future		838,000
O&M, JD per cubic meter, at start-up		0.063
O&M, JD per cubic meter, at future		0.063
Total cost, JD per cubic meter at start-up (6.6 MCM sold/yr)		**0.248**
Total cost, JD per cubic meter when 13 MCM sold/yr		**0.157**

Table 5. HZR cost estimate with tertiary two-stage lime treatment phosphorous removal.

Item		Capital Cost, JD
Rapid Mixing Basins		330,000
Flocculators		1,300,000
Clarifiers		2,000,000
Filtration Facilities (for 13 MCM, expandable)		2,400,000
Pump Station, civil works		220,000
Pumps (4 x 150 HP each)		220,000
Meters, valves, air release valves		200,000
Storage Reservoir (18,000 cubic meters)		2,400,000
Backup Chlorination system		220,000
Yard piping		400,000
	Subtotal	9,690,000
Electrical (10%)		969,000
	Subtotal	10,659,000
Contractor OH and Profit (25%)		2,664,750
	Subtotal	13,323,750
Contingencies (10%)		1,332,375
	Subtotal	14,656,125
Transmission main to external storage tank		
	17 km of 600 mm DI pipe at 150 JD/m	2,550,000
	Subtotal	17,206,125
Design, Engineering (7%)		1,204,428
Land Acquisition		120,000
	TOTAL	18,530,553
Debt Retirement Factor (6.5%, 25 years)		0.0819
Annual Cost of Capital		1,517,652
Estimated Annual Component of Cap Cost (JD per cubic meter) at startup (6.6 MCM)		0.230
Estimated Annual Component of Cap Cost (JD) per cubic meter at future capacity (13 MCM)		0.117
Annual O&M		
Labor		
	Start-up (12 hrs/day)	100,000
	Future (24 hrs/day)	200,000
Chemicals (lime, chlorine and filter aid)		
	Start-up (12 hrs/day)	300,000
	Future 24 hrs/day	600,000
Sludge Handling		
	Start-up (12 hrs/day)	150,000
	Future (24 hrs/day)	300,000
Power		
	Start-up 12 hrs/day	100,000
	Future 24 hrs/day	200,000
Materials		
	Start-up (12 hrs/day)	100,000
	Future (24 hrs/day)	200,000
O&M per year, start-up		750,000
O&M per year, future		1,500,000

O&M, JD per cubic meter, at start-up	0.115
O&M, JD per cubic meter, at future	0.115
Total cost, JD per cubic meter at start-up (6.6 MCM sold/yr)	**0.345**
Total cost, JD per cubic meter when 13 MCM sold/yr	**0.232**

IX. Bulk Reclaimed Water

One approach for quickly starting a reclaimed water program is to provide at a treatment plant a bulk source of reclaimed water. Developing such a program for the Amman-Zarqa basin could have many benefits, among them helping catalyze thinking about municipal reuse options in a step-wise manner. The basic idea is constructing a storage tank for filling tanker trucks, which in turn distribute the reclaimed water for non-potable uses. A concept diagram of such a system is shown in Figure 4.

Planning a bulk reclaimed water program helps address a number of important issues. These considerations include developing and promulgating standards for reclaimed water which could result in incidental public contact, and regulations governing end-uses of the reclaimed water. As noted above, reclaimed water which could come in contact with workers or the public should be secondary effluent, filtered so that disinfection effectiveness will be maximized and to maximize the time a chlorine residual will last. The reclaimed water production facilities will require on-line monitoring of turbidity and chlorine residual, and valving for preventing water not meeting the standard from reaching the storage tank. After a given time interval, unused reclaimed water should be returned from storage to the treatment plant, to maintain chlorine residuals.

A bulk reclaimed water source at the new As Samra treatment plant can have many uses. These uses include construction, sewer cleaning, park areas and other ornamental irrigation along roadways, for example. Further, such a program helps introduce to the public and others the concept of using reclaimed water for non-agricultural purposes.

Hauling distances will of course affect the economics of transporting reclaimed water. Given the rapid population growth and plans for housing up to 450,000 persons on the site of an old military camp, many opportunities for municipal application of reclaimed water supplied by a bulk station may exist.

The physical facilities for storing and providing bulk reclaimed water include piping (painted Pantone Purple 522C), a storage tank, and appropriate signage. Training for those who pick up and use the reclaimed water will be necessary. Such controls could be similar to the methods controlling bulk well water supplied by the fleets of green trucks throughout Jordan.

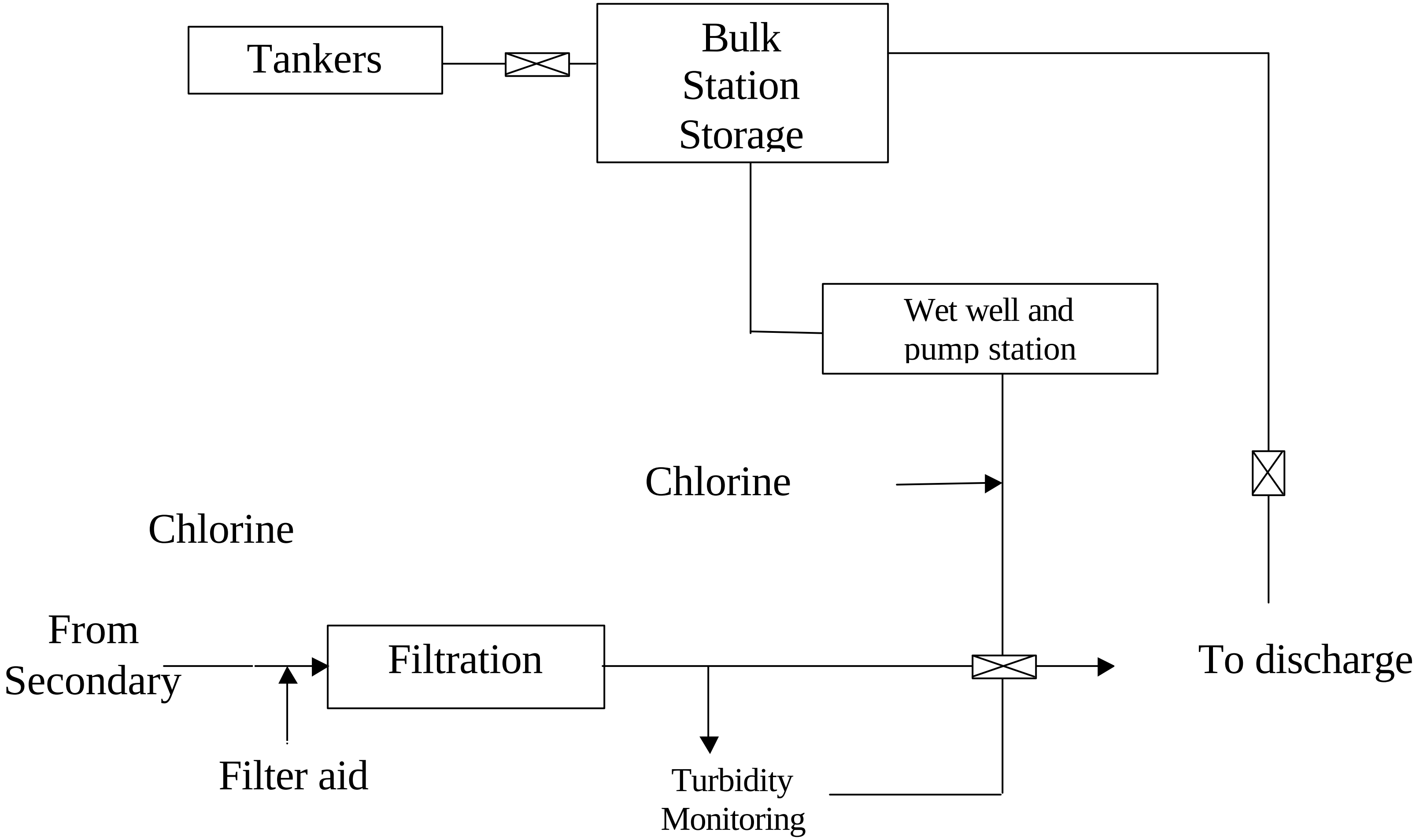


Figure 4. Concept diagram of a bulk reclaimed water system

X. Other Treatment Plants in the Basin

Three other potential sources of reclaimed water in the basin are Jerash (east), Abu Nuseir, and Baq'a. In addition, new plants are planned for Jerash (west) and Zarqa. Details can be found in MWI/ARD (2001a).

In general, the Jordanian standard for BOD_5/TSS of 50-50 mg/l, and PO_4-P of 15 do not bode well for non-agricultural reuse options. The BOD_5 and TSS values are not indicative of full secondary treatment, and the high discharge TSS values suggest difficulties with filtration and lower disinfection effectiveness than when suspended solids are at 30 mg/l (or lower following filtration). The high phosphorous concentration also makes it necessary to reduce phosphorous if reclaimed water is to be used for recirculated cooling. Thus, the plants at Jerash (east) and Baq'a do not appear to have good prospects for non-agricultural reuse.

The projected effluent values for a new Jerash (west) plant and the anticipated future Abu Nuseir plant effluent quality indicate that, under the right circumstances, these facilities could be developed into water reclamation plants for non-agricultural reuse (other than cooling). It has been reported that monitoring at the smaller treatment plants in the basin is much less thorough than at As Samra. Thus, a wholly different approach to these plants would be necessary for considering non-agricultural reuse there further.

In the event of motion toward developing these smaller facilities as water reclamation plants, then reuse options and approaches are similar to those discussed above. The primary focus would be on municipal uses for the more remote plants, while the new facility at Zarqa could possibly serve industrial users if a market can be developed. Considerations regarding standard-setting and regulation, planning as well as design aspects are similar to those described above for As Samra.

XI. Legal and Administrative Mechanisms

There appear to be few legal restrictions for use of reclaimed water. However, as detailed in this report, it will be important to institute appropriate treatment, water quality and distribution system standards for all non-agricultural uses. During a site visit to the oil refinery, it was noted that mists from cooling towers can and do reach plant employees. When there are any such possibilities for public contact, then standards described above should be developed and applied by legal and regulatory bodies. These approaches will require teamwork and planning by MWI, probably in conjunction with the Ministry of Health, to develop appropriate regulatory mechanisms and controls.

XII. Acceptability

The acceptability of a non-agricultural reuse program will depend on a number of driving factors. These factors include cost, and development of standards and appropriate oversight programs, which may vary with intended reuse applications. It is most cost effective to develop a program meeting the broadest number of uses possible. In this way, specialized needs by industrial reclaimed water users are met by further on-site treatment. Large industrial users should be viewed as partners in the planning process; their acceptance can be earned through their involvement in this way. Public acceptance can be gained by involving appropriate community leaders through an open planning and implementation process.

XIII. Summary and Conclusions

Various non-agricultural uses of water reclaimed at the new As Samra facilities may be possible in the Amman-Zarqa basin. These uses include industrial cooling; irrigating sport areas, parks, ornamental gardens, and nurseries; toilet, urinal flushing, and air conditioning in large commercial and public buildings in newly developing areas; and construction. Successful development of a non-agricultural reuse program will depend on number of important factors. As discussed below, these factors pertain to treatment and distribution facilities, creating appropriate regulatory approaches, liaison with potential users, planning, and implementation.

The new As Samra plant must in all respects be considered a "water reclamation plant," <u>not</u> a "wastewater treatment plant." This perspective includes design, operations and maintenance aspects. Appropriate redundancies and back-up facilities must be present, and design factors pertaining to sustainability and operability in Jordan will require careful thought at all stages.

Discharge limits reported for the new As Samra treatment plant indicate reclaimed water at the facility could be used for a number of non-agricultural reuse options. These limits include BOD_5 and TSS levels of 30/30 mg/l, which are tighter than the current 50/50 standard in Jordan. At start-up, depending on design approaches, the system may produce water with quality somewhat better than the design parameters, assuming the plant is underloaded. Lime treatment for phosphorous removal is necessary before As-Samra effluent can be used for recirculated cooling. In addition, tertiary filtration is a recommended component of treatment for non-agricultural reuse options. Filtration will significantly improve water quality, improving effectiveness of disinfection while lengthening the time for chlorine residual dissipation. Two stage lime treatment followed by filtration at As-Samra plant is an option that should be studied in more detail. By this the water that reaches the industry would have a quality that is suitable for recirculated cooling. Further treatment by the industry is necessary if reclaimed water is to be used for other purposes that require higher quality water.

While plant designs are being developed and during design reviews, it will be optimal to involve potential users of reclaimed water in the planning process. This approach is particularly applicable to nearby large users of ground water for cooling and other process uses (the existing oil refinery and a future electric power plant), which are excellent candidates for using reclaimed water. In this manner, potential users can learn and provide input as to their needs.

Planning for non-agricultural reuse will in fact require cooperation among all concerned parties (including policy-makers, regulators of both water and wastewater, potential users of reclaimed water, key members of the public and others as appropriate). This group should establish mutually-agreed-upon goals and objectives for a non-agricultural reuse program, mapping out the planning process in a logical, but flexible way. Planning must address many factors, including standards setting, regulation, informing the public, reclamation facilities design and operation, follow-up, market development, financing, and design and construction of transmission and storage facilities. Acceptable level(s) of commitment by potential users should receive due attention during planning.

Preliminary planning stages include evaluating potential users near the reclamation plant. This process was begun during project activity, revealing promise for serving large industrial cooling water needs at Jordan Petroleum Refinery, the existing 99 MW power station, and a new 450 MW power station. These pre-feasibility investigations indicate that water reclaimed at the new As Samra plant could be used for cooling water make-up (88 m^3/hr) at the oil refinery after phosphorous removal. Refinery personnel have concerns, however, about reliability and some water quality parameters (ammonia and organics). They are willing to discuss use of appropriate chemical additives with their chemical supplier, and express interest in possibly joining the reuse planning process.

The existing 99 MW power plant uses small quantities of cooling make-up water. However, power plant personnel suggest considering heat exchanger approaches that would replace some groundwater consumption with reclaimed water while increasing plant efficiency. Both the refinery and the existing power plant, and the new 450 MW generating facility can become partners for developing realistic approaches to fulfilling their cooling and other process water needs.

Cooling water volumes will be substantial after the new power plant comes online. This facility is predicted to require 5.5 MCM of cooling water per year, while the oil refinery cooling water make-up is 0.6 MCM per year. Further studies, including pilot plant work, will be necessary components of maximizing use of reclaimed water by industrial facilities. With addition of treatment and storage capacity, the refinery and the existing power plant could substitute (i.e. exchange) virtually all ground water withdrawal with reclaimed water. At that stage, predicted expansion at the oil refinery would result in its using 3.9 MCM per year, while the power plant would use 0.61 MCM per year of reclaimed water. Note that after use, process (including cooling) water must be considered industrial wastewater and regulated accordingly.

Municipal uses of reclaimed water may, under the right circumstances, also be possible near the new As Samra plant. One approach for municipal use of reclaimed water is through constructing a dual distribution system: one for potable and the other for non-potable water. Economics of constructing dual distribution systems can be favorable when new areas are being developed. This approach may be considered for the East Zarqa Planning Area, the former site of the military camp, which is to house 450,000 persons within the next fifteen years, and will include commercial, public, and residential construction. Dual systems will require developing municipal codes regulating distribution of reclaimed water. Requirements such as signs, back-flow prevention, and other construction prerequisites must be codified. In addition, careful attention must be paid to developing standards that protect the public in the event of incidental contact. While not recommended for residential reuse here, a dual system serving this area could serve numerous public and commercial needs including irrigating ornamental areas, horticulture businesses, fire fighting, air conditioning large buildings, and possible construction uses.

Appropriate standards must be developed for public or other uses that could result in incidental human contact. These standards include the following recommendations: filtration of secondary effluent, chlorination to 1 mg/l and maintained at 0.5 mg/l in the distribution system, and a maximum turbidity average of 2 NTU.

Provided that reliability and public health concerns can be met, there is merit in considering a reclaimed water distribution backbone supplying large industrial users and to the East Zarqa Planning area. This distribution backbone (the HZR option in this pre-feasibility analysis) would feed reclaimed water to the refinery and to the existing and new power plants, and to the East Zarqa planning area, while allowing for future expansion. Capital cost was estimated to be approximately 14,900,000 and 18,500,000 JD in case phosphorous removal was practiced in the primary clarifier and after secondary treatment, respectively. Assuming that 6.6 MCM per year of reclaimed water are sold at start-up and that the system is financed at 6.5 % for 25 years, reclaimed water charges would be approximately 0.25 and 0.35 JD per cubic meter, respectively. At a future use of 13 MCM/year, reclaimed water charges would be reduced to about 0.16 and 0.23 JD per cubic meter, respectively (because increasing reclaimed water sales would be paying off a fixed annual loan payment).

There may be merit in considering a bulk reclaimed water distribution system serving non-potable needs near As Samra. Such a program can be a means for addressing many non-agricultural reuse issues, without the high cost of a transmission and distribution system. Bulk programs help inform the public about water reuse, preparing for using greater volumes in the future.

A number of further studies are recommended. These recommendations include sponsoring studies of concrete and soil compaction with reclaimed water. The power plant and oil refinery should be brought into the planning process and begin studies, both paper and pilot, targeting using reclaimed water. In addition, it will be helpful to evaluate approaches and costs that the oil refinery and existing power plant would incur in adding treatment facilities for meeting their entire water requirements.

References

Asano, T. (Ed.), *Wastewater Reclamation and Reuse*, Technomic Publishing Co., Lancaster, PA and Basel, 1528 pp (1998).

ASTM, "Standard Specification for Ready-Mixed Concrete," C 94/C 94M, ASTM (2001).

Goldstein, D.J. and Casana, J. G. "Municipal Wastewater Reuse in Power Plant Cooling Systems" chapter 19 in "Water Reuse", Middlebrooks E. (Ed.), Ann Arbor Science, 1982.

Harza, et al., "Master Plan and Feasibility Study for Rehabilitation for Rehabilitation, Expansion and Development of Existing Wastewater Systems in Amman-Zarqa River Basin Area, Plan Year 2025, Part Three, Wastewater Conveyance, Treatment and Reuse," July 1997.

Manual of Practice SM-3, "Water Reuse", Water Pollution Control Federation, 1989.

MEM (Ministry of Energy and Minerals), 2001. Private Project for Generating Electricity. Letter to Ministry of Water and Irrigation, Amman, Jordan.

MWI/ARD. 2001a. Characterization of Wastewater Effluent in the Amman-Zarqa Basin. Water Reuse Component Working Paper, Water Policy Support, Ministry of Water and Irrigation, Amman, Jordan.

MWI/ARD. 2001b. Standards, Regulations & Legislation for Water Reuse in Jordan. Water Reuse Component Working Paper, Water Policy Support, Ministry of Water and Irrigation, Amman, Jordan.

MWI/ARD. 2001c. Plan for Managing Water Reuse in the Amman-Zarqa Basin and Jordan Valley. Water Reuse Component, Water Policy Support, Ministry of Water and Irrigation, Amman, Jordan.

Okun, D.A., personal communication, 2001.

Schimmoller, Larry et al., Reuse Pilot Testing with High Rate Filtration Pays for Clarification, AWWA,WEF Water Reuse Conference Proceedings, 2000.

Shaner, W.W. 2001. Economics Study for Managing Water Reuse in the Amman-Zarqa Basin & the Jordan Valley. Water Reuse Component Workinh Paper, Water Policy Support, Ministry of Water and Irrigation, Amman, Jordan.

US Environmental Protection Agency (US EPA), *Guidelines for Water Reuse*, EPA/625/R-92/004, September 1992.

Appendix A

Use of As-Samra Effluent in Once-through Cooling Systems

Once-through cooling systems receive water from its source, pass it through the cooling system to cool process equipment and then discharge it after a single use to the receiving body of water. The water quality of once-through systems does not need to be nearly so high as for recirculating systems. Once through systems often are used on coastlines, where seawater is passed through cooling units and returned at elevated temperature. Once-through cooling systems require as high as 10 times, or even more, the water required for recirculating systems. As-Samra reclaimed water has a good potential for use in once-through cooling systems taking into account that the quality of water used in these systems is not critical. Moreover, the increase in concentration of constituents that cause problems in cooling water does not occur in these systems, as it does in recirculating systems.

Problems that could occur in cooling systems when As-Samra reclaimed water is used for cooling, either once-through or recirculating systems, are scaling, corrosion, biological growth, fouling, and foaming. These problems are discussed in more detail below:

- Scaling : Scaling is the formation of hard deposits on heat exchanger surfaces thus reducing heat exchange efficiency. It is usually caused by calcium (as carbonate, sulfate, and phosphate) and by magnesium (as carbonate and phosphate) deposits. Silica also causes the formation of scales that are hard to remove. Pretreatment of cooling water and/or chemical additions can be used to lower the concentration of scale-forming constituents, and to reduce scale formation potential. If high concentration of phosphate is present, as is the case in As-Samra effluent receiving secondary treatment, calcium phosphate deposits are the first to form. Phosphorous precipitation by lime or inorganic coagulants is used to control phosphorous concentration to reduce scale forming potential. The reduction of the concentrations of calcium and magnesium by lime softening or ion exchange can also be used, although ion exchange is comparatively expensive. Reverse osmosis is another expensive alternative used for the removal of scale forming constituents. Acids like sulfuric, hydrochloric, and citric acids or special chemicals like polyphosphates may be applied to increase calcium and magnesium water solubility. Chemical scale inhibitors like organic phosphorous compounds, polymeric organics, or inorganic polyphosphates are used to keep scale forming materials, especially calcium based, in solution at concentrations much higher than what is expected. Silica scales, however, cannot be prevented by these methods, therefore its concentration has to be kept below its solubility limit.

- Corrosion: Corrosion in cooling systems causes equipment destruction and deposition of corrosion products, which reduces heat exchange efficiency. Corrosion increases as concentrations of total dissolved solids, dissolved gases (oxygen and carbon dioxide), temperature, and certain metals (manganese, iron, and aluminum) with high oxidation potential increase. Corrosion inhibitors like chromates, polyphosphates, and zinc, can be applied to control corrosion. Some of these substances contaminate the cooling water and may have to be removed from water blowdown prior to discharge to the wadis or the collection system, according to the relevant Jordanian standard. Reclaimed water is usually more corrosive than freshwater due to higher TDS concentrations. Therefore it requires higher dosages of corrosion inhibitors. For As-Samra reclaimed water, the TDS concentration, however, is lower than the well water that is being used by the oil refinery or the power plant.

- Biological Growth: Biological growths decrease the heat transfer efficiency of cooling systems, and can lead to corrosion under the biological deposits. Nutrients such as nitrogen and phosphorous, and high organics concentration in reclaimed water support the growth of slime forming organisms. Since reclaimed water contains higher concentrations of organic matter, it usually requires more biocide dosage than freshwater supplies. Of the different kinds of biocides, chlorine is the most used chemical. For reclaimed water, chlorine is also required to protect the health of the workers who may come in contact with it, especially through drift from cooling towers.

- Fouling : Fouling is the settling and attachment of suspended solids, silt, biological growth, corrosion products, and inorganic scales in cooling systems. It results in both equipment plugging and decrease heat exchange efficiency. Fouling is controlled by either removing the particulate matter through clarification and filtration, and/or by adding chemical dispersants. Chemical dispersants, like polyacrylates, prevent the agglomeration and thus, the settling of the particulate matter. Chemical treatment processes for phosphorous removal from reclaimed water can also reduce the suspended solids concentration.

- Foaming : Foaming is caused by the presence of industrial detergents, which are usually measured by Methelene Blue Active Substances (MBAS) test. Foaming can cause reduced heat exchange efficiency and deposits. Anti-foaming agents and flotation are used to reduce foaming problems.

Maximum concentrations of water quality parameters in once-through cooling systems using freshwater, and brackish water (Metcalf and Eddy 1991), along with the corresponding projected values at As-Samra are shown in Table A1:

Comparing the projected As-Samra effluent water quality with quality requirements for freshwater sources, the following points can be made:

- The concentrations of TDS and COD in As-Samra effluent are higher than the requirements set above for freshwater sources. Higher TDS values would increase the rate of corrosion and may require the use of higher dosages of corrosion inhibitors. However, the TDS concentration in As-Samra effluent is much lower than sea water that has been used in once-through cooling systems for decades. It is also lower than the recommended concentration of TDS in recirculating systems (see next section) which is 2500 mg/l. In addition, the TDS value in As-Samra effluent is lower than the TDS values of the groundwater presently used for cooling in the oil refinery and the power plant. Higher COD values would require the use of higher disinfectant dose, as one would expect for a reclaimed water source.

Table A1. Maximum concentrations of water quality parameters for use in once-through cooling systems for freshwater sources and brackish water. As-Samra projected quality is also shown for comparison

Constituent	Fresh Water Concentration (mg/l)	Brackish water Concentration (mg/l)	Projected As-Samra Concentration (mg/l)
TDS	1000	35,000	1,220
TSS	5000	2,500	30
COD	75	75	200
PH	5.0-8.3	6.0 – 8.3	8.0
Hardness ($CaCO_3$)	850	6,250	485
Chloride	600	19,000	350
Alkalinity	500	115	425*
Silica (SiO_2)	50	25	Not available
Sulfate	680	2,700	26
Calcium	200	420	95
Bicarbonate	600	140	520
DO	>0	>0	4.7
Oil and grease	No floating oil	No floating oil	8 (FOG)

* calculated

- Silica concentration in As-Samra effluent is not available.
  For a more complete analysis and evaluation of the applicability of As-Samra effluent for cooling, Silica concentration should be included in the current monitoring programs of As-Samra effluent. Silica concentration is specially important in recirculating systems.

- Phosphorous and MBAS concentrations are not included in the Table A1.
  The presence of a high concentration of phosphate in As-Samra effluent along with a high calcium concentration, would suggest that scaling resulting from the formation of calcium phosphate would have to be carefully investigated. The reduction of pH may be necessary to avoid this problem. The presence of a high MBAS concentration in As-Samra effluent would cause foaming problems.

- Floating Oil and Grease is not expected to be a problem if floating oil is removed in the new As-Samra plant prior to secondary treatment. This is a common practice in wastewater treatment plants.

The USEPA has suggested the following guidelines for reuse of reclaimed water in once-through cooling systems (Asano et al. 1998):

- Secondary treatment
- PH : 6 – 9
- BOD : less than 30
- SS : less than 30
- Fecal Coliform : less than 200 / 100 ml
- Chlorine residual : more than 1 mg/l

These guidelines have been introduced mainly to protect the health of workers from cooling tower drift. Comparing the projected As-Samra effluent (MWI/ARD, 2001a) with the USEPA guidelines, it can be seen that As-Samra effluent exceeds the guidelines in fecal coliform concentration. It should be noted however, that if residual chlorine is maintained at concentrations higher than 1 mg/l in As-Samra effluent, the fecal coliform concentration might decrease below 200 per 100 ml. If this is the case, then the As-Samra effluent can be used for once-through cooling without further treatment by the industry, except for scaling, corrosion and other inhibitors.

Although the use of As-Samra reclaimed water in once-through cooling systems can be considered as a non-consumptive use, the large quantity of water required in these systems makes it impractical. For the oil refinery, for example, the recirculation rate in the cooling system in 1995 was approximately 3,000 cubic meter per hour (Harza Inc., 1995). In addition, higher quantities of chemicals are also required. The high quantity and high temperature of water used for cooling can result in higher temperature in wadi Zarqa if it is used as the receiving body of water. Therefore it is necessary to recirculate water in order for the industries to use reasonable quantities of cooling water. Only a small cycles of concentration (COC) value would reduce the quantity of water required substantially.

Appendix B

Comparison between the projected As-Samra effluent and the current groundwater used at the oil refinery and the power plant.

Table B1 shows the projected As-Samra effluent without tertiary treatment (phosphorous removal) and the present water quality of the wells used for cooling in the oil refinery and the power plant makeup water. It can be seen that As-Samra effluent for a number of parameters is superior to the present well water used in the oil refinery and the power plant. Concentrations of calcium, magnesium, TDS, and hardness in the projected As-Samra effluent are about two thirds of their corresponding concentrations at the power plant wells. Sodium, Chloride, and Sulfate concentration are about three fourths, one half, and one tenth, respectively. Similarly, the ratios of these parameters compared to their concentrations in the oil refinery wells are even less, ranging from one tenth for sulfate, to one third for sodium and chloride, to one half to two thirds for Ca, TDS, and Hardness. Magnesium concentration is 80%. However, As mentioned earlier, the projected As-Samra effluent is expected to have a number of concerns that are typical of a secondary effluent, and not of a freshwater source. These are ammonia, nitrate, phosphorous, detergents, suspended solids, and organics. These concerns have been discussed earlier, and with the necessary treatment, these factors are not expected to limit the recirculation of cooling water.

As mentioned earlier, the quantity of water required for cooling is dependent on the cycles of concentration in the cooling system. The present makeup water is 88 and 8 cubic meters per hour, for the Jordan Petroleum Refinery, and Hussein Power Plant, respectively. These quantities are for a two cycles of concentration. If 1.3, 1.5, or 3 cycles of concentration were used for As-Samra effluent, then the sum of makeup water for both the oil refinery and the power plant would become 207, 144, and 72 cubic meters per hour, respectively, assuming that the evaporation water volume would remain the same.

The table also shows that if TDS value is the factor than limits the use of only 2 cycles of concentration for the well water in the power plant and the oil refinery, then the reclaimed As-Samra effluent can be used for 3 cycles of concentration. This will lower the quantity of water required by about 25%. As will be shown later, from other experiences around the world, the projected As-Samra effluent after the two stage lime treatment for phosphorous removal may be used for more than 3 cycles of concentration.

- Palo Verde Nuclear Generating Station (Asano 1998).

The Palo Verde Nuclear Generating Station uses reclaimed water for recirculating cooling system. The wastewater receiving secondary treatment is then treated on the nuclear power plant site using two stages cold lime/soda ash softening system followed by gravity filtration. This treatment train was found to be the most cost effective for Ca, Mg, Silica, and Phosphorous removal. For 15 cycles of concentration the required quality for makeup water was:

- SS : < 10 mg/l
- Turbidity : < 15
- Orthophosphate : < 0.5 mg/l

Table B1. Comparison between the projected As-Samra effluent with current water used by the Jordan Petroleum refinery and Hussein power plant.

Parameter	Projected As-Samra	Power Station makeup (avg. of 5 wells)	Oil Refinery well water (different than makeup	Oil Refinery makeup (calculated) assuming 100% removal by R.O.
Ca	95	153	214	165
Mg	60	97	85	66
Na	230	306	750	580
K		7.5	9	7
NH_3-N	15	0.2		
SO_4	26	219	286	221
Cl	350	665	1121	866
NO_3	31	20	29	22
PO_4	46	0.0282		
SiO_2		16.3	24	19
PH	8	7.21	7	7
BOD	30			
COD	200			
Al	0.3			
Fe	0.19	0.07		
Mn	0.09			
TDS	1220	1870	3317 (cond.)	2560 (cond.)
Hard. ($CaCO_3$)	484	704	812	627
Alk. ($CaCO_3$)	425	219	242	187
MBAS	20			
SS	30			
Turbidity				

- Calcium : < 28 mg/l (70 mg/l as $CaCO_3$)
- Alkalinity : < 100 mg/l as $CaCO_3$
- Silica : < 10 mg/l as SiO_2
- Magnesium : 2.5 mg/l (10 mg/l as $CaCO_3$)
- Ammonia : < 5 mg/l

- Amarillo (Goldstein and Casana, 1982)

Amarillo wastewater treatment plant secondary effluent receives cold lime treatment, reacidified for storage, and then circulated at pH 7 for slightly more than 5 cycles of concentration. Water quality parameters that are relevant to reuse in cooling towers in Amarillo and other locations are shown in Table B2.

This table suggest that the use of As-Samra effluent after two stage lime treatment in recirculating cooling towers using 15 cycles of concentration should be considered. The expected concentrations of a number of constituents in As-Samra effluent after two-stage lime treatment are within acceptable ranges for being used in 15 cycles of concentration cooling towers. A pilot plant for this option is necessary. This option has the advantages that the volume of water required for cooling is reduced to a minimum. Very small volumes of blowdown water are discharged, which have very high TDS values. This would make the possibility of using evaporation ponds to solve the problem associated with high TDS values in blowdown water more economically feasible. Lower evaporation pond volumes would then be necessary for this purpose.

These preliminary investigations suggest that use of reclaimed water by the oil refinery and the existing and proposed power plants is an excellent possibility. It is suggested these establishments be brought in as partners in the planning process for reclaimed water use. In-depth studies will be required for them to learn how best to make use of reclaimed water when it becomes available. It is likely that pilot plant work will be necessary, both for learning how and for optimizing reclaimed water use, and these studies will require time and effort. On-site storage and treatment trains for serving one or more of these facilities can be considered, so that over time their full water requirements could be served with reclaimed water. Further discussion of reclaimed water consumption by these facilities is detailed below in considering details of the HZR option.

Table B2. Water quality in a number of locations using reclaimed water for cooling, along with suggested recommendations. Some expected As-Samra effluent parameters after two-stage lime treatment are shown for comparison.

Parameter	Amarillo Sewage Effluent	Makeup, Amarillo	Cooling water after 5+ COC (Amarillo)	Palo Verde Nuclear Generating Station (for 15 COC)	Weddle and Rogers (for 15 COC)	Goldstein and Casana, 1982 (for 15 COC)	As-Samra After PO_4 removal
Ca	74	72	360	28	28	25	20
Mg	36	10	50	2.5	2.4	15	5
Na	584	584	2994				230
K	20	20	100				
NH_3 -N	73	73	8	4	4	**	15
HCO_3	220	40	32				
CO_3	0	60	0				
SO_4	293	350	1800				26
Cl	443	443	2215				350
NO_3	5	4	145				31
PO_4	51	2	10	0.5	1.5	1.5	1
SiO_2	28	10	50	10	10	10	10
PH	7.3	9.2	7.0				9
BOD	15	2	6		10	**	
COD							100
Al							
Fe							0.19
Mn							0.09
TDS	1400						1220
Hardness ($CaCO_3$)		222*	1150*				70
Alkalinity ($CaCO_3$)				100			
MBAS							2
SS				10	10	**	10
Turbidity				15			2